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Can Auctions Control Market Power in Emissions Trading Markets?

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Abstract

Using eight sessions (twenty-four ten-period markets) in a double ABA cross-over design, we demonstrate clear evidence of market power in double-auction emission trading markets (agents who are not constrained to only buy or sell). Conventional theory predicts that in half of the market-power environments monopsony should emerge and in half monopoly should emerge. Market-power outcomes are frequently observed, most often in the form of price discrimination, and most effectively by monopsonists.

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Introduction

Emissions trading is frequently advocated as an instrument for market-based environmental regulation. Unfortunately many potential emissions trading markets are likely to be sufficiently concentrated to create market power. In particular, it is frequently thought that the United States will effectively be a monopsonist in any international emissions trading under the Kyoto protocol. If market power is exercised, emissions trading may fail to achieve an efficient allocation of responsibilities for abatement. Moreover, the gains from trade may be reallocated inequitably.

The exercise of market power may be constrained by the trading institution within which contracts are formed. In particular, it has been suggested that the double auction market is particularly resistant to market power. This suggestion is based on laboratory evidence. Smith (1981) found that monopolists trading in a double auction market experienced difficulty in maintaining monopoly prices. Monopolists in his double oral auctions were able to obtain only about 25 percent of the potential monopoly price increase (for the last period), in contrast to their ability to achieve 100 percent of the potential increase under a posted bid institution.[2] Smith and Williams (1989) replicated this experiment and found much lower prices; on average their monopolists achieved only about 6 percent of the potential price increase in the last period. Smith and Smith and Williams explain this result by postulating that buyers' resistance to high prices is

[1] The funding for the laboratory sessions described in this paper were from a McMaster University Arts Research Board grant to R. Andrew Muller. The paper has benefited from comments by Tim Cason, Dan Friedman, and Rob Moir.

[2] See Table 13 and sources cited there.

increased once the monopolist reveals himself prepared to sell at lower prices.

Further experiments have confirmed that firms can exercise market power more easily in a posted-price environment than in a double auction environment. After summarizing laboratory work in this area, Holt (1995, p. 398) concludes that "sellers are sometimes able to exercise market power in double auctions, but the influence of seller market power is much weaker (in the double auction) because of the incentives to offer last-minute price concessions and the more active role that buyers have in this institution." Since the monopolist cannot pre-commit to the monopoly price as trading progresses, it lowers its price when gains from trade still exist at the end of a trading period. As these price reductions become public knowledge, in succeeding periods more buyers wait for the price reductions, causing the monopolist's market power to be eroded further, as it may be more profitable for the monopolist to make some sales at competitive prices than no sales at all.

Such results have led some to suggest that potential market power in emissions trading can be controlled by using double auctions (Bohm 1998). We argue that the existing laboratory evidence is too weak to support this policy conclusion, for a number of reasons. The claims for the double auction are based on very few laboratory sessions (three for Smith, five for Smith and Williams) and these were not exactly comparable. Moreover, Smith's original experiments showed substantial output restriction under monopoly (on average his monopolists traded 2.28 units less than the competitive output, or 76 percent of the predicted output restriction of three units), so that efficiency may suffer in double auction markets even if prices are not raised. Finally, neither experiment provides a controlled contrast between competitive and monopoly environments.

It may be particularly difficult for double auctions to control market power in emission trading markets. Emission trading markets exhibit some special features not always found in the paradigmatic buyer/seller markets investigated by Smith. One is that sellers of emission permits generally have the option of earning profits by using unsold permits in their own operations. The Smith environment does not reflect this aspect of the field: his sellers are given marginal cost schedules. They earn no profits at all unless they trade. An alternative is to assign to the sellers redemption values similar to but lower than the buyers' values. Selling a coupon then represents a foregone redemption value. This may create a frame in which sellers may be less vulnerable to counter-withholding by buyers. Another special feature of many emissions markets is that agents can act as traders, buying and selling permits for resale or repurchase. This does not affect predicted prices under competition or single price monopoly, but it may introduce more noise into the price structure and lead to unknown dynamic effects.

Several experiments have detected market power being exercised by dominant firms in double auction markets for tradable emission permits. Ledyard and Szakaly-Moore (1994) adapted Smith's parameters to an emissions trading environment by allowing all agents to buy and sell coupons. It appears, however, that they continued to provide sellers with a marginal cost schedule rather than redemption values. In two of three sessions they discovered a "strong" monopolist who was able to achieve earnings close to those predicted for a single price monopolist. Even in the last period of the experiment the strong monopolists were able to achieve about 25 percent of the potential monopoly price increase (mean prices for the weak

monopolist were actually below competitive equilibrium).[3]

Brown-Kruse, Elliott, and Godby (1995) also detected market power in laboratory markets related to emissions trading. In their experiment single buyers or single sellers of emission permits with a capacity to use ten permits participated in a market with ten sellers or ten buyers of one permit each. The value of a permit was derived from the cost savings it permitted the subject. The subject with market power had information about the cost schedules of the remaining participants. In the last period of their sessions, monopolists achieved an average of 40 percent of the potential price gain and monopsonists 166 percent of the potential price reduction.[4]

Godby (1999, 2000) replicated many of these results in a market which allowed trading. He aggregated the ten smaller agents in the Brown-Kruse, Elliott and Godby experiment into five composite subjects with the capacity to use two permits each, while retaining a single buyer or single seller with the capacity to use ten permits. All subjects were permitted to both buy and sell permits in the same period. In the last period of the experiment his monopsonists achieved an average of 147 percent of the available price reduction. His monopolists were not so successful. Despite a pattern of high prices in earlier periods, by the tenth period transactions prices in the monopoly market were below competitive levels.

In short, the limited laboratory evidence suggests that it is premature to be sanguine about

[3] The potential price increase is derived from predictions for a monopolist who posts a single price throughout a period. See data and sources in Table 13 below.

[4] These data refer to "simple manipulation". Brown Kruse, Elliott, and Godby also considered "strategic manipulation", under which agents with market power had an incentive to alter their permit purchases to affect conditions in a downstream market.

the ability of double auctions to control market power. Further investigation is required before reaching a definite conclusion. In particular, it would be useful to directly contrast the performance of competitive and monopoly markets under the same set of underlying cost conditions. This paper presents such an experiment. We create a laboratory market in which ten traders are given redemption value schedules and allowed to trade permits. Five are expected to be net buyers of permits, five net sellers. We then aggregate either the five buyers into a single monopsonist or the five sellers into a single monopolist. Thus we consider market power both on the selling side (monopoly) and on the buying side (monopsony). Unlike all previous experimenters, who have adopted a between-sessions design for investigating this problem, we adopt an ABA crossover design to allow for fuller experimental control over subject effects. In this design we control for subject effects by allowing the same group to participate in both market power and competitive environments. Within any one session we switch between competition and a market power and back again. This allows a powerful contrast between the two market structures.

The present experiment is directed at establishing a more general research program into the exercise of market power in auction markets. We focus first on establishing a baseline design and second on confirming the existence of market power. If market power is found in these sessions, a broad-ranging research program into the determinants of that power becomes very attractive. If market power is not confirmed we will be in a position to support the policy recommendations alluded to above.

Experimental Design

We created a market environment in which ten subjects traded coupons in a computerized

double auction. Subjects were informed that they each represented a firm which produced a product from several inputs. One input, called *leets*, was rationed. Each period the firm received revenues from selling its product and incurred costs from purchasing inputs. The difference between revenues and the cost of all inputs except leets was denoted net sales revenue. Leets could be used to reduce costs. The sum of this cost saving and the net sales revenue was the firm's *total operating profit*. The marginal value of a ration coupon, therefore, was the increase in total operating profit induced by employing one more unit of leets. These definitions were illustrated by Table 1, which is reproduced from the instructions.

Subjects were further told that some of them would receive shares in the ration coupons. Each share entitled the subject to one coupon per period. Coupons could be used to increase operating profits or sold to other subjects. Subjects who did not receive shares could choose to buy coupons. Once bought, these coupons could be used to increase operating profits or resold to other subjects. In this experiment, coupons are analogous to annual emission permits. Shares are analogous to a permanent entitlement to a flow of annual permits. We adopted the shares/coupons terminology prevent the subjects' being influenced by emotional reactions to the concept of emissions trading and to be consistent with the terms used in the software.

Subjects traded coupons in a computerized double auction market.[5] They were guided in their trading by a *wizard*, a small window which informed them how much adding or subtracting one coupon from their holdings would change their operating profits. A market consisted of a number of trading periods. At the end of each trading period, subjects were informed of the

[5] We used the RNSC double auction reported in Godby, Mestelman, Muller and Welland (1997) and described in more detail in Mestelman and Muller (1998).

redemption value of their coupon holdings, their net sales revenue and their operating profit for the period. Total earnings, including profits from trading, were continuously displayed in an inventory screen. Total earnings were displayed at the of each market.

Each experimental session contained four markets: one practice market lasting two or three periods of 10 minutes each and three data markets lasting for 10 periods of three minutes each. Subjects recorded their earnings at the end of each data market. At the end of the session they were paid their earnings privately in cash.

The redemption values used in the experiment are derived from those used by Smith (1981), Smith and Williams (1989) and Ledyard and Szakaly-Moore (1994). The original parameters were expressed as supply and demand schedules. They induced a single competitive equilibrium price, an efficient trading quantity of eight, and a market power equilibrium quantity of five. We made four adjustments. First, we eliminated the need for commissions by raising the demand curve and lowering the supply curve to create an equilibrium price tunnel of five cents. Secondly, we altered the supply curve to maintain the three unit separation of the competitive and market power predictions. Thirdly we expressed the sellers' marginal opportunity costs as redemption values. Finally, we introduced fixed costs and revenues computed so as to induce a profit of 100 cents per period for each player when coupons are efficiently allocated and the market price is at the mid-point of the equilibrium price tunnel (87 cents). These baseline parameters are reported in Table 2 and are reflected in the supply and demand schedules shown in Figures 1 and 2.

We considered three market structures: competition, monopoly and monopsony. In the baseline (competitive) environment, each agent received two redemption values. The five agents

with lowest valuations each received two coupons per period. These agents were expected to be net sellers of coupons. The five agents with highest valuations received no coupons. These agents were expected to be buyers. In the monopoly environment we simulated a merger among the five sellers by combining their redemption values schedules into one. The remaining four sellers were "locked out" of the market, however they still received fixed revenues sufficient to yield profits of 100 cents per period. Similarly, the fixed costs of the monopolist were raised to yield an expected profit of 100 cents at the efficient allocation. The monopsony treatment was like the monopoly treatment, expect that the buyer's schedules were combined. The monopoly and monopsony parameters are reported in Table 3 and are reflected diagrammatically in Figures 1 and 2 respectively.

As noted, each of the sessions consisted of a practice market (denoted Market 0 in this paper) and three real markets (denoted Markets 1, 2 and 3 in this paper). Different redemption values were used in each market. The redemption values in the practice market bore no relationship to the values in the real markets. The basic parameter sets of Table 2 and Table 3 were used in Market 1. In the Market 2 all redemption values were displaced downwards by subtracting 23 cents from each coupon value. In Market 3, all redemption values were displaced upwards by 26 cents from the baseline values. Fixed revenues were adjusted to maintain a proft of 100 cents for each agent under an efficient allocation.

Each session required 10 subjects. The unpaid practice market lasted for one or two periods of ten minutes each. During this time, subjects were carefully instructed in the use of the software.[6] Following this, all ten subjects participated in all three markets for that session.

[6] Instructions are available from R. Andrew Muller(mullera@mcmaster.ca).

Monopoly and monopsony market structures were independently contrasted with competition in two ABA crossover designs (see Table 4). During the market power sessions (monopoly or monopsony) the four subjects who were shut out of the market were invited to observe the trading or to read a book. Their attention was drawn to the experiment, however, because interaction with the computer software was required at the beginning and end of every period, even for the shut-out subjects.

Benchmarks and Predictions

We computed trading volumes, prices, profits and gains from trade under four benchmark predictions (Table 5). The no-trade benchmark, obviously, represents the result of the initial distribution of coupons. With this allocation, buyers earn 244 cents per period and sellers earn 305 cents, for a total of 549. Gains from trade are the increase in profits from these benchmark. The competitive (or efficient) benchmark is the configuration which maximizes the total gains from trade. With this allocation, buyers and sellers both earn 500 cents per period, a gain of 256 cents for buyers and 195 cents for sellers. Total profits rise to 1000 cents, thus the total gains from trade are 451 cents.

The monopoly and monopsony benchmarks are the configurations which would maximize the gains for a single seller or a single buyer posting a single price. The monopolist would post a price of 113 cents per unit, the monopsonist 61 cents. Under the benchmark monopoly allocation, five coupons would be sold. The sellers collectively would earn 601 cents, of which 400 would be fixed revenue payments to the inactive sellers and 201 would be the profit of the monopolist. Buyers collectively would earn 344 cents per period. Gains from trade are 296 cents for the single seller and 100 cents for the buyers collectively. Total gains from trade are 396 cents, or

87.8 percent of the total possible gains of 451. Under the benchmark monopsony equilibrium five coupons would also be sold. The buyers collectively would earn 604 cents (for a total gain of 104 cents), of which 400 cents accrue to the inactive participants. The sellers collectively earn 341 cents (for a total gain of 36 cents). Overall efficiency is 87.8 percent, the same as in monopoly. The benchmark prices and quantities are displayed in Figures 1 and 2.

Results

We ran a pilot session and four data sessions in late April and May 1999 and four additional data sessions in July 1999. Four subjects, who were to be given the role of monopolist or monopsonist, were recruited from post-doctoral fellows and graduate students in economics and business. The remaining thirty-six subjects were recruited from the general student population through advertisements and classroom announcements. Sessions were planned to last for no more than 3 hours. Due to computer failures in a number of runs, the sessions lasted somewhat longer, up to 3½ hours. On these occasions, subjects gained additional trading experience in the aborted sessions. Due to the length of the sessions, three subjects had to be excused (one in session 990501a and two in session 990506b) . These were replaced by available graduate students (one in Mathematics and one in Economics), who had participated in a pilot session the previous week. Because of the length of the session, the competitive market in the third session (990506b) was terminated after 8 periods. After each session was over subjects completed a debriefing questionnaire and were paid privately in cash. The competitive subjects earned between $11.82 and $36.23 (mean $26.22) for their participation, plus a $5.00 show-up fee. The subjects with market power earned $39.13 to $66.91 (mean 48.16; see Table 6).

We first present a graphical overview of transactions prices in the eight sessions. We then

turn to numerical analysis of mean prices, volumes, profits, effectiveness and efficiency. In general we compute each of these values by period and average over the observed periods (generally 10) in each market. Accordingly, we have one observation for each market in each session, for a total of 24 observations. Although the graphical and tabular results speak for themselves we also report statistical tests of the null hypotheses that treatment (monopoly, monopsony or competition) and market sequence (one, two or three) have no effect on the mean values of these variables. These tests are based on one-way and two-way analysis of variance. We recognize that the reported significance tests are conditional on the independence of errors across observations. While this is clearly true across sessions, it is equally clear that the results in Markets 2 and 3 of any given session might be dependent on the subjects' experience in preceding markets. We believe we have reduced the potential for such interdependence by averaging over all of the observations in a market. In any case, the overwhelming apparent statistical significance of most our results suggests that they are unlikely to be altered by more elaborate statistical methods.

Prices

Figure 3 gives an overview of transaction prices by market structure.[7] The three time-series are the means in each trading period of the median prices in each period across twelve competitive markets, six monopoly markets and six monopsony markets. The aggregated data for the competitive markets clearly reflect the conventional result that competitive market prices tend to converge to the competitive equilibrium price in a double-auction environment. The median

[7] The redemption value and marginal cost schedules were displayed in the second and third markets of each session. The prices reported in the discussion below are normalized to be comparable to the prices in the first market of each session.

prices in the markets in which traders had market power are not drawn into the competitive equilibrium price band (85 to 89 cents). Monopoly prices tend to stabilize above the competitive equilibrium price band while monopsony prices stabilize below this band. Monopoly prices are further from the predicted single-price monopoly price of 113 cents than are monopsony prices from the single-price monopsony price of 61 cents.

The aggregated data of Figure 3 do not reflect the variation in price patterns that were generated across sessions and markets. Figures 4, 5 and 6 display a distinctive switching pattern between competitive and market-power treatments. The convention used in these figures is to represent markets 1, 2 and 3 with a circle, square, and triangle respectively. Closed symbols and bold lines reflect market-power environments. The data are the means in each trading period of two sessions of the median prices in each period. In Figure 4 the monopoly market was sandwiched between two competitive markets (the CSC session). The tendency was for prices to rise from the competitive market to the monopoly market and return to the competitive price in the subsequent market. Figure 5 displays the same pattern for the CBC sessions, where the price during the monopsony market falls below the prices in the competitive markets between which it is sandwiched. Figure 6 displays the price summary for the BCB sessions in which the competitive market is sandwiched between two monopsony markets. Figure 7, summarizing the SCS sessions, does not display the switching pattern. The relatively high monopoly market 1 prices are followed by lower competitive market 2 prices, but the market 3 monopoly prices do not rise above the competitive market prices.

The upper portion of Table 7 reports mean prices by type of session and market. The mean prices for CSC, CBC and BCB sessions are consistent with the switching pattern just

discussed. The lower portion of Table 7 reports mean prices by treatment and market. The mean price over all competitive sessions is about 86 cents, within the competitive equilibrium band of 85 to 89 cents. The mean monopoly price is about 101 cents, much above the competitive band but distinctly below the benchmark monopoly price of 113. The mean monopsony price is about 66 cents, somewhat above the benchmark of 61 cents. Conducting a two-way analysis of variance on session and market and on treatment and market, we retain the null hypothesis of no market sequence effects ($p = 0.2100$ and $p = 0.2516$ respectively) and strongly reject the hypothesis of no session or treatment effects ($p = 0.0003$ and $p = 0.0000$ respectively).

Overall, Figures 4 - 7 and Table 7 give clear evidence that switching between competitive and market power treatments reliably induces a switch between competitive and market power price patterns. Monopoly environments reliably raise mean prices and monopsony environments reliably reduce them.

Output and Efficiency

We define net purchases as the difference between the number of coupons bought and sold. Since there is no coupon banking, this is also the number of coupons redeemed. Detailed examination of the data reveals an anomaly. In exactly one of the 118 periods we recorded the appearance of phantom coupons. In that period alone the software appears to have permitted two subjects to sell more coupons than they owned, so that their net purchases were negative. We have excluded this period from the following tabulations.

There is some evidence that output was restricted in our market power environments, however the extent of restriction is much less than predicted by theory. Table 8 reports mean net purchases of coupons by treatment and market. Recall that the benchmark net purchases are eight

in competition and five both in monopoly and monopsony. Table 8 indicates an observed mean of 7.07 coupons in competition and 6.72 coupons in the monopoly treatment and 6.09 coupons in the monopsony treatment. We retain the null hypothesis that a three-way treatment classification has no effect on net purchases. If, however, we combine the monopoly and monopsony categories, we can weakly reject the null of no effect of market power (ANOVA, $p = 0.0709$) while the null of no market sequence effect is maintained (ANOVA, $p = 0.7118$). Note that these are two-tailed tests.

The relatively small output restriction suggests that we will not find that efficiency is significantly affected by market power. This is confirmed by Table 9, which tabulates efficiency by treatment and market. On average our markets were quite efficient, achieving 91 percent of available gains from trade. One quarter of the individual markets (the two monopsony Markets 1, one monopsony Market 3, one monopoly Market 2, one competitive Market 1, and one competitive Market 3) exhibit substantially lower efficiencies (between 83 and 85 percent). The null hypothesis of no treatment or market effects is easily retained, however ($p = 0.5250$ and $p = 0.2737$ respectively). This pattern suggests that the monopolists and monopsonists may have succeeded in a substantial degree of price discrimination.

Profits and Effectiveness

Although output was not greatly restricted by the exercise of market power, the distribution of profit certainly was. Table 10 reports profits by role, treatment and market. These profits include the fixed net revenues paid to inactive traders. The observed profits should be read in conjunction with the benchmarks of Table 5. Consider the buyers. There is substantial variation among the observations. Nevertheless, in competitive markets they earned an average of

500 cents per period, exactly the benchmark profit. In monopoly markets their profits fell to 364, slightly above the benchmark of 344. In monopsony markets their profits rose to 601, somewhat below the benchmark of 604. Sellers' mean profits were 458 cents in competition (below the benchmark of 500), 602 under monopoly (barely above the benchmark of 601), and 350 (slightly above the benchmark of 341). The treatment effect is statistically significant (one-way ANOVA, $p = 0.0000$ for buyers and for sellers). We conclude that market structure has affected the distribution of profits in much the same manner as predicted by single price monopoly theory.

The distribution of profits differs according to market structure and there is evidence that market structure systematically affected the ability of buyers or sellers to achieve their benchmark profits. We define an effectiveness index equal to the ratio of the buyers' or the sellers' gains from trade relative to their predicted gains from a no trade baseline under the given market structure. The results are reported in Table 11 and summarized in Figure 8. For buyers, the average effectiveness indexes are 1.00 for competition, 1.20 for monopoly, and 0.99 for monopsony. This indicates that buyers did better than predicted in monopoly environments and about as well as they were expected to do in competitive and in monopsony environments. When the other side had the market power, the buyers achieved substantially more than their predicted profits. Sellers did best when buyers had market power (an effectiveness index of 1.24) and relatively poorly under competition (index of 0.78). When they had market power, sellers did about as expected (index of 1.01). These results depend heavily on variations across the market sequence, however. In the final market, buyers quite systematically earn more than predicted and sellers earn less. In the first market, buyers in monopoly and sellers in monopsony environments are distinctly disadvantaged. Experience in competitive and market power environments appears

to have an impact on the distribution of gains from trade. Analysis of variance on these data retains the null hypothesis of no effect of market structure ($p = 0.6364$ and $p = 0.6013$ for buyers and sellers respectively) or market sequence for sellers ($p = 0.5130$). However the null hypothesis of no effect of market sequence can be marginally rejected for buyers ($p = 0.0722$).

Speculation

Participants in these sessions are not restricted to either buy or sell coupons. In the role of traders, individuals who might ultimately be net sellers of coupons may purchase coupons for later sale if they believe that this is a profitable activity. With the ability to speculate, the number of transactions which take place in any trading period may greatly exceed the predicted equilibrium number of trades. Table 12 shows the mean purchases of coupons per period by treatment and market sequence. On average, in competitive markets more than 11 coupons are traded in each period, but only 7 net purchases are made. Nearly 40 percent of transactions are speculative. Approximately 26 percent of the transactions in monopoly markets are speculative while fewer than 5 percent of monopsony market trades were speculative. With respect to mean coupon purchases, the treatment effect is significant (ANOVA, $p = 0.0484$).

The large number of trades which took place in the competitive markets may have contributed to the relatively low efficiency (91 percent) in these markets as compared to competitive markets in which participants act as either buyers or sellers. Speculative purchases in the markets with traders introduce sufficient noise that even the double auction is unable to discipline trading sufficiently to guarantee that all of the gains from trade are realized.

Price Discrimination

The existence of prices significantly different from competitive prices in market power environments combined with higher than expected efficiencies in many of these markets (see Table 9 and compare the monopoly and monopsony efficiencies in markets 1 through 3 to the predicted efficiency of 87.8 percent) suggests that price discrimination may characterize the price behaviour in these markets.

Figure 9 displays the contract prices by period as they were generated in the first CSC session. Contract prices in the first market (S1M1 C) shows many more than eight trades in each period and contract prices that are range between the single-price monopoly price of 113 cents and the single-price monopsony price of 61 cents. The traders are inexperienced and appear to be overwhelmed with their ability to speculate. In the second market (S1M2 S), in which there is a single seller, contracts are formed initially at prices above 113 cents, period after period, and fall throughout each period, usually ending at a price in, or close to, the competitive equilibrium price band. This appears to reflect effective price discrimination. Trading in a double auction does not result in prices uniformly converging to the competitive equilibrium price after several trading periods. Finally, in the third market (S1M3 C), five sellers and five buyers quickly converge into the competitive equilibrium price band. With the exception of several trades at exceptionally low prices, this market conforms to our expectation of trading in a double auction with five buyers and five sellers.[8]

[8] The low prices may arise from speculation that fails. If a high valuation trader (see Table 2), who should purchase two coupons, purchases three units quickly in a trading period, expecting to sell one for a profit later in the period, does not resell that third unit soon enough, he may sell it for whatever he can

Figure 10 displays the contract prices by period as they were generated in the first BCB session. The first market (S4M1 B) has a single buyer of coupons. In this market contracts are formed at very low prices in the first few trading periods, but these prices quickly converge near to the single-price monopsony price. By the fifth trading period contract prices are first formed at just below 61 cents and then rise towards the competitive price. In this market there is weak prie discrimination. Most noteworthy is that *opening* contract prices do not converge into the competitive equilibrium price band. The second market (S4M2 C) has five buyers and five sellers. This market ended after eight trading periods because of a computer malfunction, but eight periods were more than enough to demonstrate the expected convergence to the competitive price range. Finally, market S4M3 B once again generates monopsonistic pricing. Prices begin slightly below the single-price monopsonist price of 61 cents and fall to the competitive price range. Opening prices once again are consistently below 61 cents.

Figure 11 displays three markets in which market power appears to be exercised even when there is more than one seller! It is important to note here that in nominal terms the single-price monopoly price prediction is 113 cents and the competitive price range is between 85 cents and 89 cents in the first market. In the second market these are 90 cents and 62 to 66 cents respectively. In the third market these are 139 cents and 111 to 115 cents respectively.

The first market (S2M1 S) is a monopoly market. Prices consistently open above 113 and fall to the competitive range. The mean contract price in the last trading period is 106.3 cents and

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obtain. If there is another buyer who is waiting for the last minute for bargains is in this market, the low trade may be consummated. Because the speculator's opportunity cost of the third unit is zero, it may sell for very little. The negative value in market S1M3 C arises because the schedules in this market have been shifted up by 26 cents. Any contract at a price below 26 cents will appear as a negative value when prices are normalized.

the closing price is in the competitive equilibrium price band. This appears to be another example of price discrimination. The second market (S2M2 C) has five buyers and five sellers. The competitive equilibrium price band for this market is between 62 and 66 cents. Even though the last price seen by these traders in market 1 was approximately 85 cents the five sellers are able to keep the opening price in each period at or above 90 cents. Prices fall throughout each trading period, frequently getting as low as 40 cents (with two contracts well below 30 cents). In the final trading period the mean contract price is 72 cents and the last contract price is in the competitive equilibrium price band of 62 to 66 cents. This potentially competitive market does not converge to the competitive equilibrium price. The five sellers in this double-auction market are successful in keeping mean contract prices above the competitive equilibrium price band through the ten trading periods. Finally, when the third market, with a single seller, begins trading, the opening exceeds the single-price monopoly nominal price of 139 cents. Although the opening contract prices gradually drop below 139 cents in this market, the monopolist is able to consistently enter into contracts above the competitive equilibrium price band early in the trading period. The final period mean contract price is 117 cents, slightly above the competitive equilibrium price band of 111 to 115.

After one market of very effective price discrimination, and a second market of successful price manipulation by a group of sellers, the double-auction institution finally began to exhibit some of the discipline that we expect from it. However, even in this market prices were, on average, maintained above the competitive equilibrium price band.

The nine markets described above display clear tendencies for market power to emerge in varying degrees under double-auction trading rules. In one case a market power outcome

appeared to emerge when market power was not expected to emerge. One characteristic of these market power outcomes is the pattern of price discrimination rather than single-price monopoly or monopsony.

Discussion and Conclusions

Our results extend and confirm the findings of Brown Kruse, Elliot and Godby (1995), Godby (1997) , and Ledyard and Szakaly-Moore (1994), all of which challenge the conventional assertion that double auctions provide an effective constraint on market power. Our study is unique in employing a within-subjects design which allows us to control for subject effects more precisely than is possible in a between-subjects design. The cost of this additional control is a loss of independence between the observations within a given session. On the other hand the ability to alternate between market structures within the same session provides a rigorous test of the causal link between market structure and performance and, in our opinion, more than compensates for the statistical difficulties.

Our results clearly establish that our monopoly and monopsony subjects were able to manipulate prices to their advantage despite any limitations placed on them by the double-auction institution. This does not appear to be a transient effect which is eliminated through learning.

Figures 9 - 11 show examples of price discrimination by both monopolists and monopolists as well as evidence of some of decay in market power within markets. Of particular note is what appears to be the inability of a market without a market power agent to converge to the competitive equilibrium. The insignificant effect on efficiency and the relatively small constraint on net purchases, together with the observed price patterns, strongly suggest that efficiency losses were mitigated by price discrimination. As a result, subjects with market power

were able to increase their share of the profits substantially (relative to the competitive environments) without greatly harming efficiency.

Our results exhibit a stronger effect of market power in double auctions than was observed in most previous work. Table 13 compares the price results across our experiment and five predecessors. To allow for the possibility of convergence to competitive equilibrium a session we examine only the mean prices in the last periods reported. In the present experiment, monopolists achieved 55 percent of the potential price increase while our monopsonists achieved 65 percent of the potential price declines. The monopolists were more successful than those of previous experiments while the monopsonists were somewhat less successful in comparison.

One might legitimately ask if the success of subjects with market power is due to a lack of experience in the double-auction market. Because previous experiments ran only one market per session they provide little evidence on this score. In our sessions, however, participants in Market 3 had experience in both a competitive and a market power environment in the immediately preceding markets. Although we have only two observations per cell in this case, the results suggest a possibility that monopsony resists pressures for price erosion more than monopoly. The monopolists in this situation achieved, on average, 29.5 percent of the benchmark price deviation in the last period while the monopsonist achieved, on average, 64.5 percent. These results suggest that careful investigation of the effect of experience in these markets would be valuable.

Our work, together with the emissions trading papers cited earlier, provides a dramatic contrast to the conventional wisdom (in experimental economics at least) that double auctions can control market power. It would be useful to explore whether this contrast arises from the special characteristics of emissions trading or whether the standard results of Smith and of Smith and

Williams are in need of reinterpretation. As noted, emissions trading environments differ from the paradigmatic double-auction environment in a number of ways, including the presence of traders buying for potential resale and the fact that sellers have a highly visible use for coupons not sold.

On a broader policy level, our results suggest that it is unwise to rely on market institutions, such as the double auction, to control market power in emissions trading markets. Our evidence of successful price discrimination also suggests that the income distribution effects of market power may be more important than the efficiency effects.

Table 1. Illustrative Net Sales Revenue, Operating Profit, and Redemption Values from Instructions

Units of Leets	Coupons Required	Net Sales Revenue (cents)	Total Operating Profit (cents)	Redemption Value of this Coupon (cents)	Total Value of Coupons (cents)
0	0	300	300	0	0
1	1 **owned**	300	550	250	250
2	2 **owned**	300	700	150	400
3	3	300	750	50	450

Note: Please note that this table is only an example. The numbers in the experiment are quite different.

Table 2. Basic Parameters For Competitive Environments

	Trader Numbers									
	High Valuations (Buyers)					Lower Valuations (Sellers)				
	1	2	3	4	5	6	7	8	9	10
Net Sales Revenue	34	44	52	56	58	-109	-87	-74	-74	-74
Coupon Allocation	0	0	0	0	0	2	2	2	2	2
Redemption Value										
Coupon 1	153	143	133	123	113	122	100	85	77	70
Coupon 2	80	84	89	95	103	52	52	52	52	61
Profit in Efficient Allocation	100	100	100	100	100	100	100	100	100	100

Note: Profit in efficient allocation includes both net trading revenue and the value of coupons redeemed.

Table 3. Basic Parameters For Market Power Environments

	Monopoly									
	High Valuations (Buyers)					Lower Valuations (Sellers)				
	1		3	4	5	6	7	8	9	10
Net Sales Revenue	34	44	52	56	58	100	100	100	100	-818
Coupon Allocation	0	0	0	0	0	0	0	0	0	10
Redemption Value										
Coupon 1	153	143	133	123	113	0	0	0	0	122
Coupon 2	80	84	89	95	103	0	0	0	0	100
Coupon 3	0	0	0	0	0	0	0	0	0	85
Coupon 4	0	0	0	0	0	0	0	0	0	77
Coupon 5	0	0	0	0	0	0	0	0	0	70
Coupon 6	0	0	0	0	0	0	0	0	0	61
Coupon 7	0	0	0	0	0	0	0	0	0	52
Coupon 8	0	0	0	0	0	0	0	0	0	52
Coupon 9	0	0	0	0	0	0	0	0	0	52
Coupon 10	0	0	0	0	0	0	0	0	0	52
Profit in Efficient Allocation	100	100	100	100	100	100	100	100	100	100
	Monopsony									
	High Valuations (Buyers)					Lower Valuations (Sellers)				
	1	2	3	4	5	6	7	8	9	10
Net Sales Revenue	-156	100	100	100	100	-109	-87	-74	-74	-74
Coupon Allocation	0	0	0	0	0	2	2	2	2	2
Redemption Value										
Coupon 1	153	0	0	0	0	122	100	85	77	70
Coupon 2	143	0	0	0	0	52	52	52	52	61
Coupon 3	133	0	0	0	0	0	0	0	0	0
Coupon 4	123	0	0	0	0	0	0	0	0	0
Coupon 5	113	0	0	0	0	0	0	0	0	0
Coupon 6	103	0	0	0	0	0	0	0	0	0
Coupon 7	95	0	0	0	0	0	0	0	0	0
Coupon 8	89	0	0	0	0	0	0	0	0	0
Coupon 9	84	0	0	0	0	0	0	0	0	0
Coupon 10	80	0	0	0	0	0	0	0	0	0
Profit in Efficient Allocation	100	100	100	100	100	100	100	100	100	100

Table 4. Experimental Design

	Treatment		Market			
Session	No.	Symbol	0	1	2	3
990505A	1	CSC	Practice	Competition	Monopoly	Competition
990506A	2	SCS	Practice	Monopoly	Competition	Monopoly
990506B	3	CBC	Practice	Competition	Monopsony	Competition
990507A	4	BCB	Practice	Monopsony	Competition	Monopsony
990712A	5	CSC	Practice	Competition	Monopoly	Competition
990714A	6	SCS	Practice	Monopoly	Competition	Monopoly
990720A	7	CBC	Practice	Competition	Monopsony	Competition
990722A	8	BCB	Practice	Monopsony	Competition	Monopsony

Notes: Practice Markets ran for one or two 10 minute periods during which instruction was given and practice trading occurred.. Markets 1 through 3 ran for ten 3 minute periods. There were 10 subjects in each session, 4 of whom were inactive during the monopoly or monopsony markets.

Table 5. Benchmarks

Benchmark	Net Purchases	Price	Profit			Gains from trade	Efficiency
			Buyers	Sellers	Market		
No Trade	0		244	305	549		
Competition	8	85 - 89	500	500	1000	451	100.00%
Monopoly	5	113	344	601	945	396	87.80%
Monopsony	5	61	604	341	945	396	87.80%

Table 6. Mean and Range of Payoffs

	Mean (C$)	Maximum (C$)	Minimum (C$)
Fringe Subjects	26.22	36.23	11.82
Subjects with Market Power	48.16	66.91	39.13

Notes Data reported are profits earned. Subjects were paid this amount rounded up to the nearest 25 cents, plus a 5 dollar show-up fee.

Table 7. Mean Prices by Session and Market and by Treatment and Market (Number of Observations in Parentheses)

	Market			
	1	2	3	Total
Session				
CSC	86.15 (2)	101.01 (2)	77.48 (2)	88.21 (6)
SCS	108.40 (2)	98.18 (2)	95.03 (2)	100.53 (6)
CBC	86.11 (2)	79.17 (2)	85.92 (2)	83.73 (6)
BCB	55.27 (2)	79.60 (2)	63.08 (2)	65.98 (6)
Total	83.98 (8)	89.49 (8)	80.38 (8)	84.62 (24)
Treatment				
Competition	86.13 (4)	88.89 (4)	81.70 (4)	85.57 (12)
Monopoly	108.40 (2)	101.01 (2)	95.03 (2)	101.48 (6)
Monopsony	55.27 (2)	79.17 (2)	63.08 (2)	65.83 (6)
Total	83.98 (8)	89.49 (8)	80.38 (8)	84.62 (24)

Notes: Data are mean prices per period averaged over all periods of each market. Two-way analyses of variance were conducted on session and market and on treatment and market. The null of no market effect is easily retained (p=0.2100 and p=0.2516 respectively). Session effects are significant (p=0.0003) and treatment effects are strongly significant (p= 0.0000). All tests maintain the hypothesis of independent errors across markets within a session.

Table 8. Mean Net Purchases of Coupons per Period, by Treatment and Market
(Number of Observations in Parentheses)

	Market			
Treatment	1	2	3	Total
Competition	7.05 (4)	6.68 (4)	7.48 (4)	7.07 (12)
Monopoly	6.75 (2)	6.25 (2)	7.15 (2)	6.72 (6)
Monopsony	5.45 (2)	7.21 (2)	6.00 (2)	6.09 (6)
Market Power (Monopoly and Monopsony combined	6.10 (4)	6.73 (4)	6.38 (4)	6.40 (12)
Total	6.58 (8)	6.70 (8)	6.93 (8)	6.73 (24)

Notes: Net purchases are the differences between coupons purchased and coupons sold by the five agents with high valuations ("buyers"). Data are the means over the observed number of periods, excluding period 6 of market 3, session 3, during which a computer error allowed coupon use. The difference between net purchases under competitive and market power environments (an aggregated treatment effect) is marginally significant (ANOVA, $p = 0.0709$) but market effects are not significant (ANOVA, $p = 0.7118$).

Table 9. Mean Efficiency Indexes by Treatment and Market (Number of Observations in Parentheses)

	Market			
Treatment	1	2	3	Total
Competition	0.88 (4)	0.91 (4)	0.93 (4)	0.91 (12)
Monopoly	0.94 (2)	0.89 (2)	0.95 (2)	0.92 (6)
Monopsony	0.83 (2)	0.96 (2)	0.88 (2)	0.89 (6)
Total	0.88 (8)	0.92 (8)	0.92 (8)	0.91 (24)

Notes: Efficiency is the ratio of gains from trade for the period for all agents combined to the benchmark gain under competition for the period (451). Data are the means over replications of the mean efficiency over periods for the session and market. The null hypothesis of no treatment or market effects is easily retained (ANOVA, $p = 0.5250$ and $p = 0.2737$ respectively).

Table 10. Mean Profit per Period by Treatment, Market and Role (Number of Observations in Parentheses)

	Market			
Role and Treatment	1	2	3	Total
Buyers				
Competition	507 (4)	475 (4)	518 (4)	500 (12)
Monopoly	334 (2)	354 (2)	403 (2)	364 (6)
Monopsony	638 (2)	554 (2)	613 (2)	601 (6)
Sub-Total	497 (8)	464 (8)	513 (8)	491 (24)
Sellers				
Competition	441 (4)	475 (4)	450 (4)	458 (12)
Monopoly	637 (2)	598 (2)	572 (2)	602 (6)
Monopsony	286 (2)	430 (1\2)	333 (2)	350 (6)
Sub-Total	451 (8)	499 (8)	451 (8)	467 (24)
Total	948	963	964	958

Notes: Data are the mean profit per period for all five buyers or sellers respectively, including fixed net revenues. Period 6 of Market 3 in Session 3 was excluded. Data for market 2 of Session 4 (a competitive market) are the means of the 8 observed periods. The treatment effect is statistically significant (p=0.0000 for buyers, p=0.0000 for sellers).

Table 11. Mean Effectiveness Indexes by Treatment, Market and Role (Number of Observations in Parentheses)

	Market			
	1	2	3	Total
Buyers				
Competition	1.03 (4)	0.90 (4)	1.07 (4)	1.00 (12)
Monopoly	0.90 (2)	1.10 (2)	1.59 (2)	1.20 (6)
Monopsony	1.09 (2)	0.86 (2)	1.03 (2)	0.99 (6)
Total	1.01 (8)	0.94 (8)	1.19 (8)	1.05 (24)
Sellers				
Competition	0.70 (4)	0.91 (4)	0.74 (4)	0.78 (12)
Monopoly	1.12 (2)	0.99 (2)	0.90 (2)	1.01 (6)
Monopsony	-0.53 (2)	3.47 (2)	0.78 (2)	1.24 (6)
Total	0.50 (8)	1.57 (8)	0.79 (8)	0.95 (24)

Notes: Effectiveness is the ratio of the gains from trade realized by buyers or sellers collectively to benchmark profit gains for trade for that group under the given treatment. A negative effectiveness index indicates that the relevant group reduced their profit by trading. Data are means of the mean effectiveness index by period for each session and market. Data for Session 3, Market 3, Period 6 are excluded. The null hypotheses of no effect of treatment or market are easily retained for buyers (ANOVA, $p = 0.6364$ and $p = 0.5130$ respectively) but for sellers the null of no effect of treatment is easily retained while it is marginally significant for market (ANOVA, $p = 0.6013$ and $p = 0.0722$ respectively).

Table 12. Mean Purchases of Coupons per Period, by Treatment and Market
(Number of Observations in Parentheses)

	Market			
Treatment	1	2	3	Total
Competition	13.43 (4)	9.28 (4)	11.50 (4)	11.40 (12)
Monopoly	7.75 (2)	10.95 (2)	8.55 (2)	9.08 (6)
Monopsony	5.80 (2)	7.55 (2)	5.80 (2)	6.38 (6)
Total	10.10 (8)	9.26 (8)	9.34 (8)	9.57 (24)

Notes: Data are the means over the observed number of periods. The treatment effect is significant (ANOVA, $p = 0.0484$), but neither the market effect nor interaction of market and treatment effects are significant (ANOVA, $p = 0.9472$ and $p = 0.5203$ respectively).

Table 13. Mean Percentage Change from Competitive Benchmark to Market Power Benchmark in the Last Period, by Experiment and Treatment (Number of Sessions in Parentheses)

	Smith	Smith and Williams	Ledyard and Szakaly-Moore	Brown Kruse et.al.	Godby	Present Experiment
Monopoly	24.8 (3)	6.6 (5)	17.9 (3)	40 (3)	-60 (3)	55 (6)
Monosony				166.00 (3)	147.00 (3)	65 (6)

Source: Mestelman, Muller, and Godby (1998) tabulate the data for Smith (1981), Smith and Williams (1989), Ledyard and Szakaly-Moore (1994), Brown Kruse, Elliott and Godby (1995) and Godby (1997) .

Notes: All experiments except the present ran one market per session. There is evidence that repetition reduces monopolists' success in raising prices. The mean deviation in the last period of the third markets of the present experiment was 29.5 percent of the benchmark deviation for the monopolist and 64.5 percent for the monopsonist.

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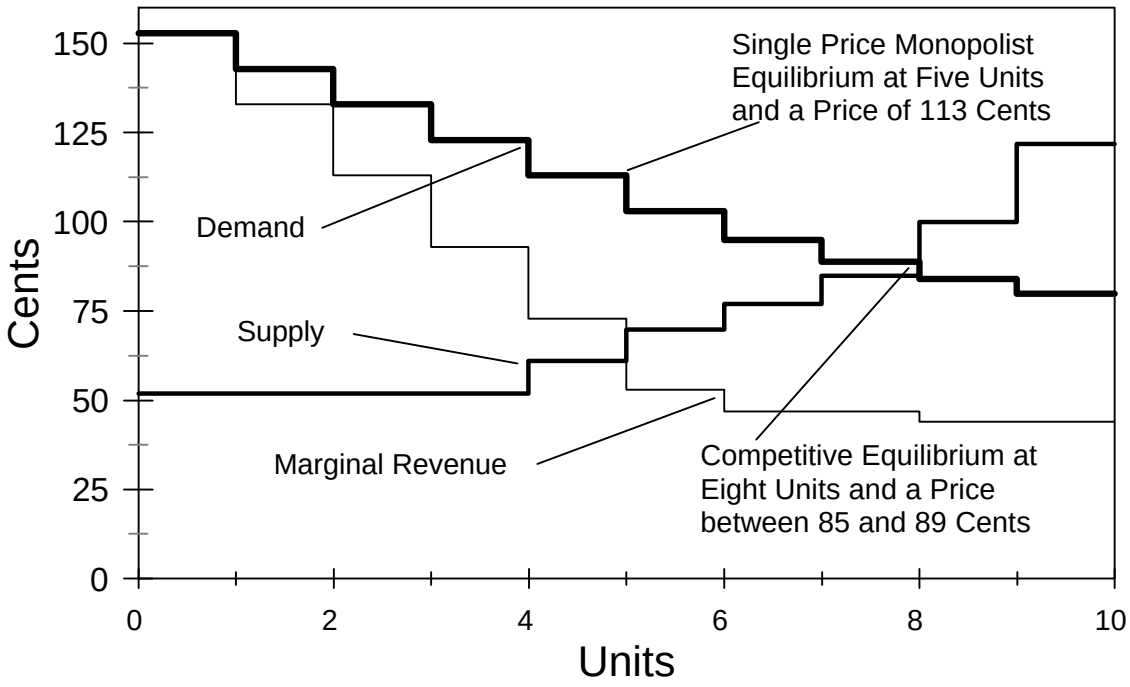

Figure 1 Supply, Demand, and Marginal Revenue Schedules

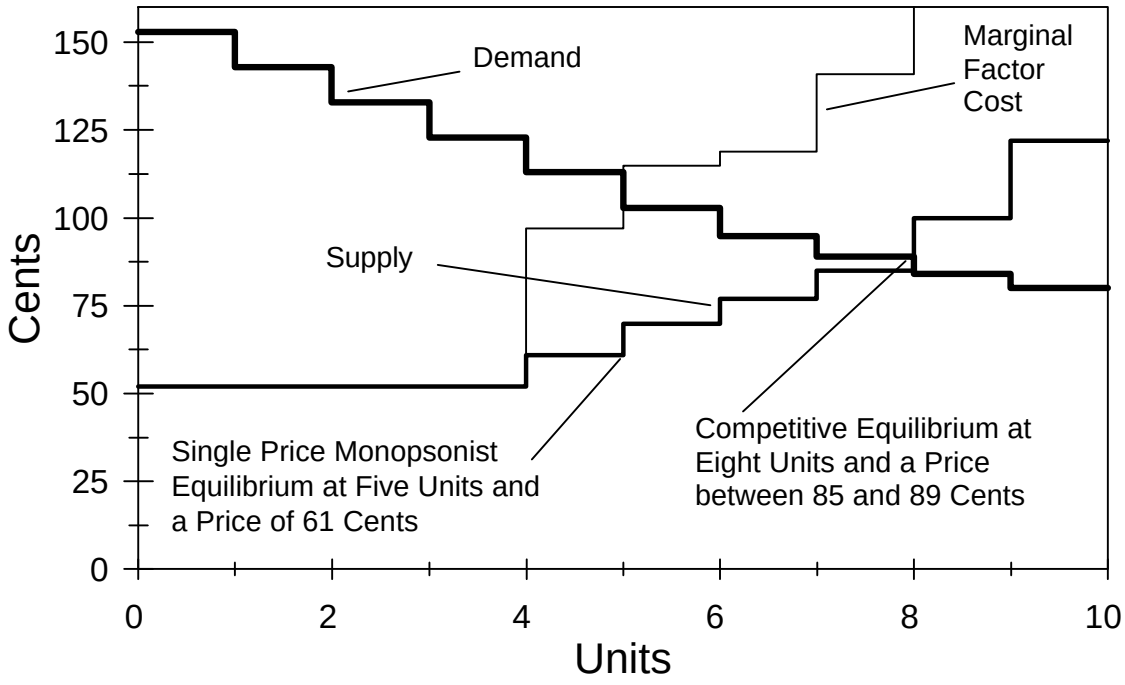

Figure 2 Supply, Demand, and Marginal Factor Cost Schedules

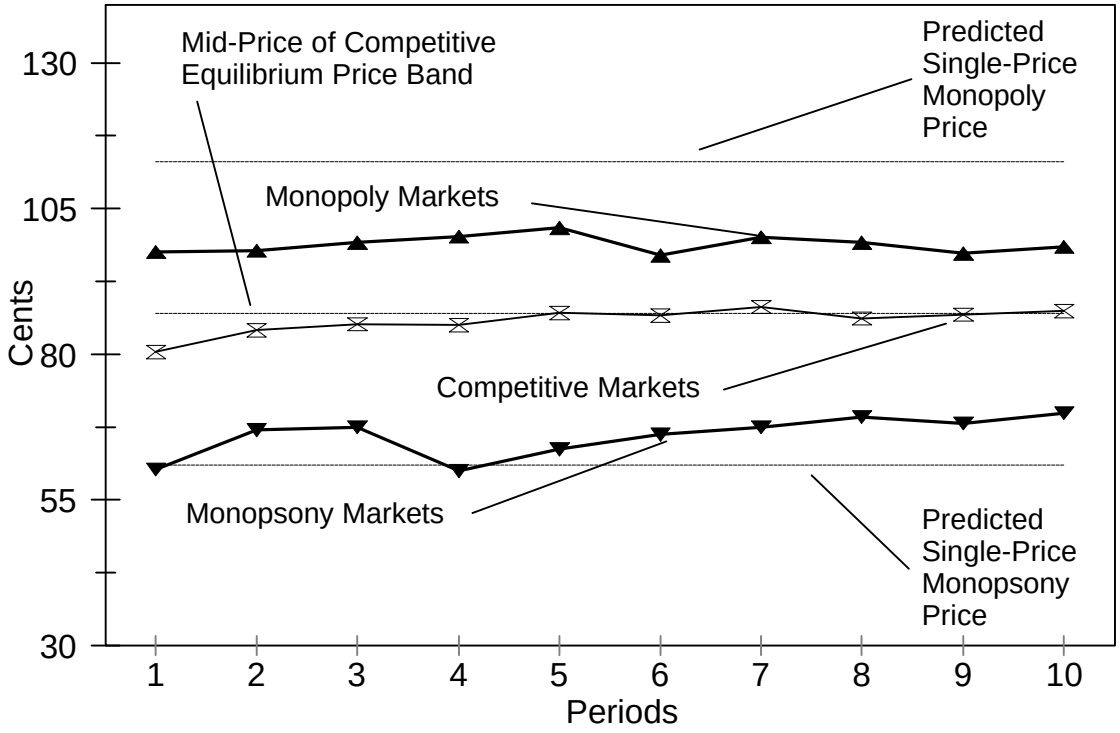

Figure 3 Mean of Median Per Period Contract Prices Across 12 Competitive, 6 Monopoly and 6 Monopsony Markets

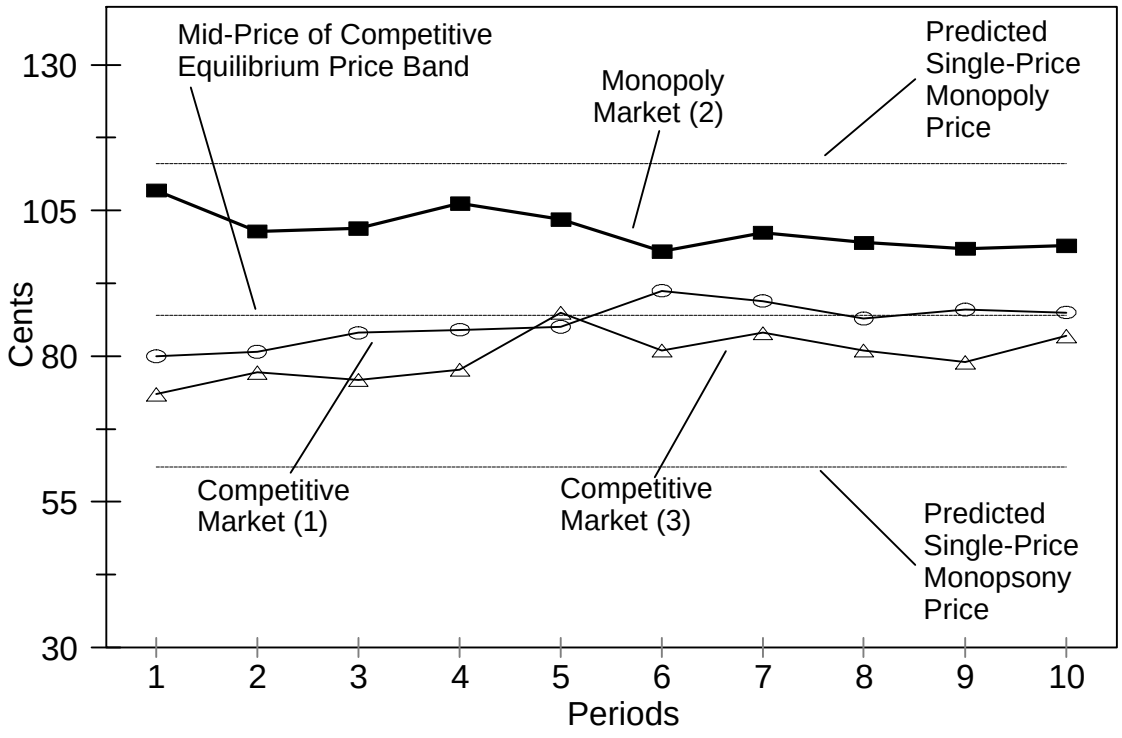

Figure 4 Mean of Median Per Period Contract Prices for Competitive and Monopoly Markets in Two CSC Sessions

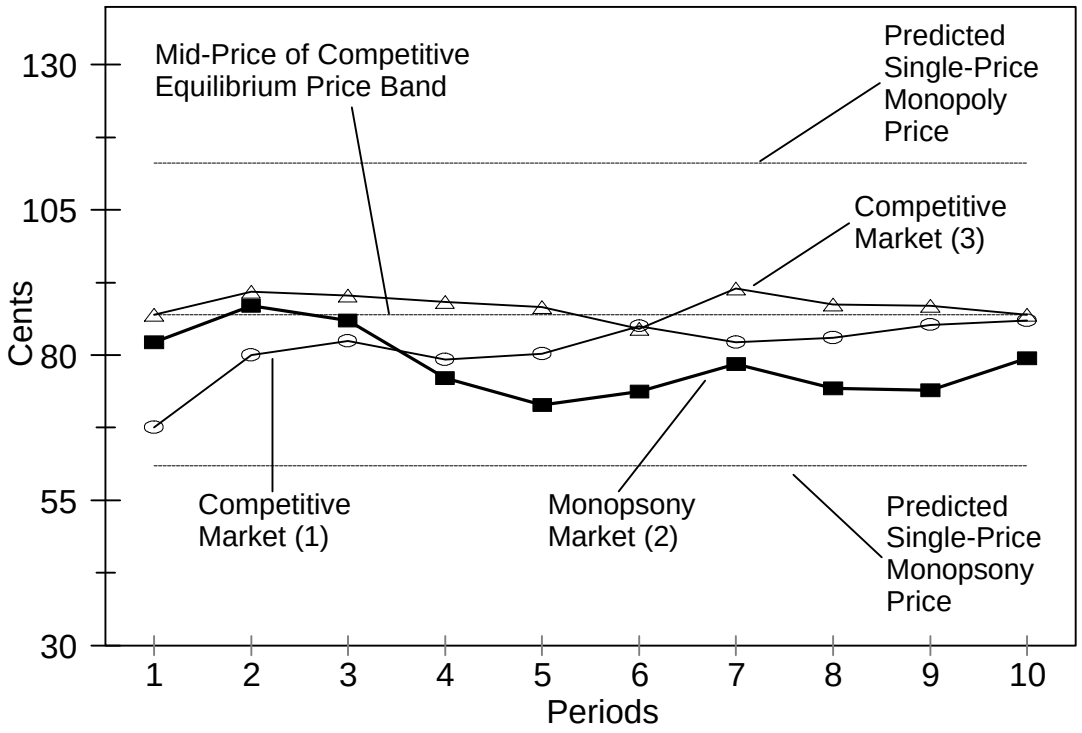

Figure 5 Mean of Median Per Period Contract Prices for Competitive and Monopsony Markets in Two CBC Sessions

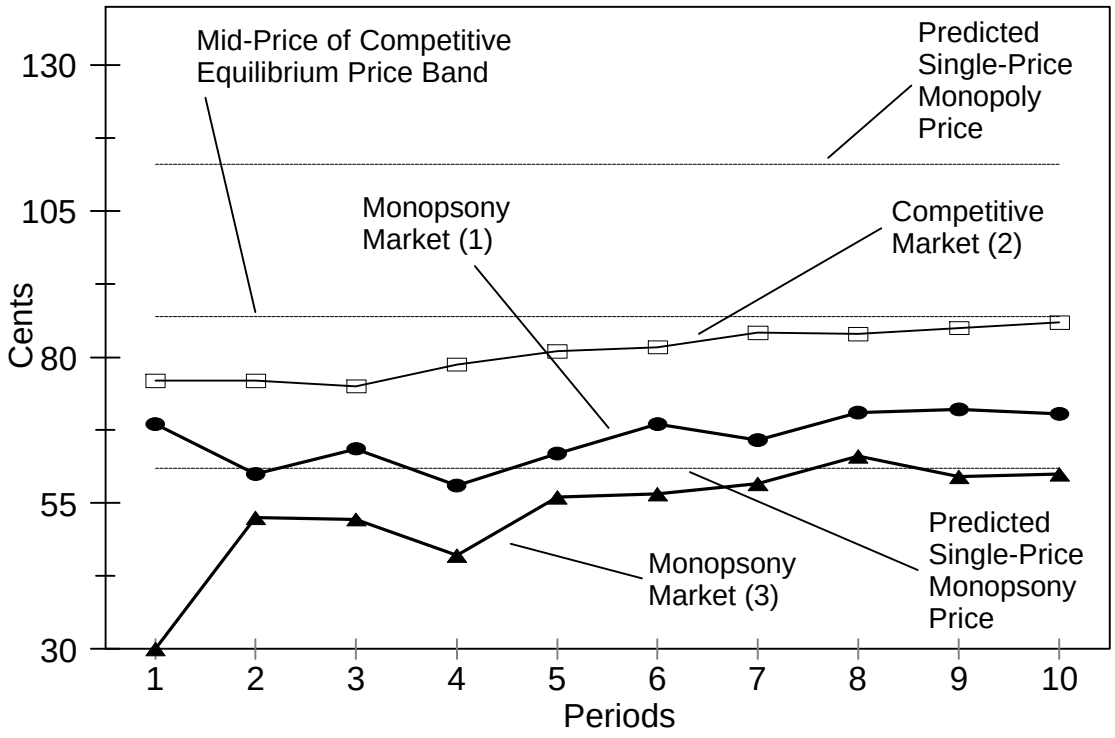

Figure 6 Mean of Median Per Period Contract Prices for Competitive and Monopsony Markets in Two BCB Sessions

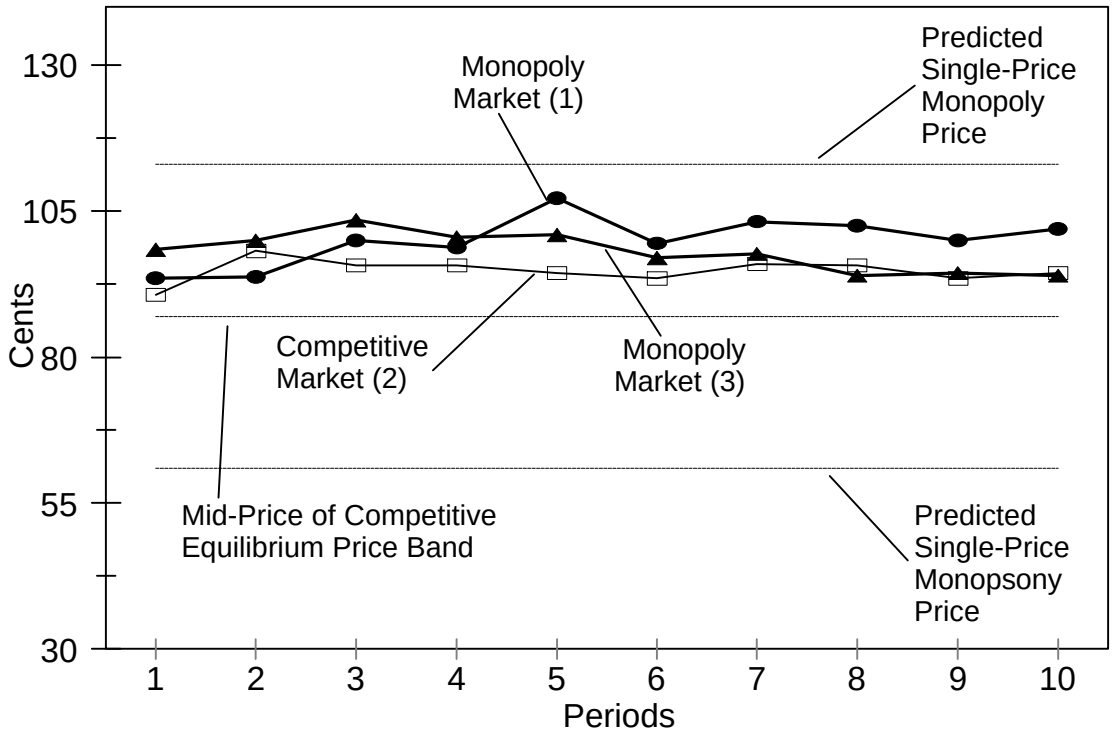

Figure 7 Mean of Median Per Period Contract Prices for Competitive and Monopoly Markets in Two SCS Sessions

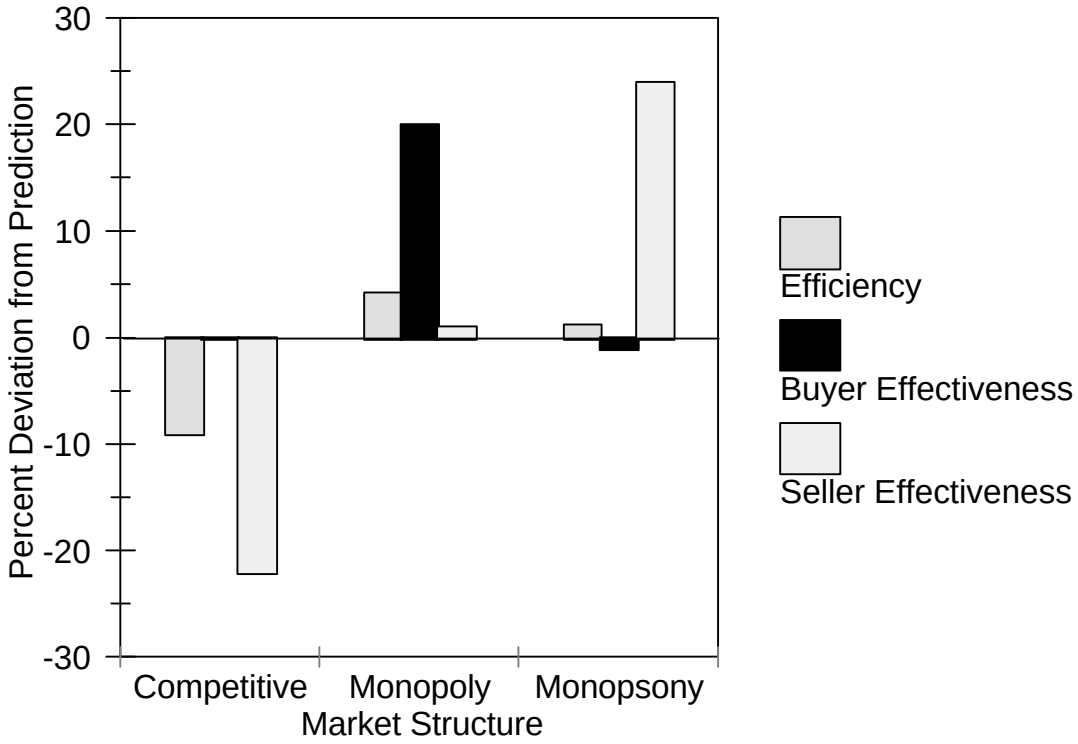

Figure 8 Percent Deviation of Efficiency, Buyer Effectiveness, and Seller Effectiveness from the Predicted Efficiency, Buyer Effectiveness, and Seller Effectiveness under Varying Market Structures

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